POWER CONVERTERS

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This report summaries the work carried out under the current Matrix Converter contract. During this period the work on the project focused on two packages of work with the objective of furthering the work on the high power inverter at ARL. The first strand of this work involves using the TI C6713 control platform and the high power inverter to control of a generator for testing on the SIL. The second strand of work is focused on supporting the miniaturization of the control platform through interaction with a third party company and developing the required interfaces for testing the inverter and control platform at the SIL in order to control both the induction motor and the generator. .

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SUMMARY

This report summaries the work carried out under the current Matrix Converter contract. During this period the work on the project focused on two packages of work with the objective of furthering the work on the high power inverter at ARL. The first strand of this work involves using the TI C6713 control platform and the high power inverter to control of a generator for testing on the SIL. The second strand of work is focused on supporting the miniaturization of the control platform through interaction with a third party company and developing the required interfaces for testing the inverter and control platform at the SIL in order to control both the induction motor and the generator.

During the period covered by this report three visits were made to the US have been made as part of this project:

1. Dr Andrew Trentin and Prof Pat Wheeler made a visit to the ARL labs near Washington DC to work on the control of the Generator.
2. Dr Lee Empringham (UoN), Dr Andrew Trentin (UoN) and Dr Robert Wood (ARL) visited the System Integration Laboratory in San Jose.
3. Dr Andrew Trentin visited ARL to demonstrate the first of the new, miniaturized DSP/FPGA control platforms.

Following the second visit to the US a report was submitted to ARL which suggested strategic objectives necessary to complete the goal of delivering a working converter to SAIC. The report also highlights potential improvements to the existing HERMIT set up which may help SAIC in achieving their goals.

This new control platform is based on the same DSP as the University of Nottingham control platform, but also includes many of the functions performed by daughter cards. This compact control platform has been defined, designed, constructed and tested in conjunction with Mann Electronic Solutions, a sub-contractor to ARL. The control platform is complemented by an FPGA board which has been design, built and tested at the University of Nottingham. At the time of writing the second of the control platforms has been completed, using the DSP and interface board designed by Mann Electronic Solutions to our specifications and our FPGA board. A further two control platforms will be finished and tested as part of the next contract. The first hardware delivered to Nottingham required significant reworking to make the connections correct, the second set of hardware was a significant improvement and it is hoped that future hardware will require far less intervention by the team in Nottingham.

1. HIGHLIGHTS

- Operation of the ARL generator under closed loop current and speed control using the original University of Nottingham control platform
- Demonstration of the large inverter hardware at the SIL testing facilities at United Defense Laboratories in San Jose, USA
- The successful design, implementation and testing of the miniaturized control platform in collaboration with Stann Electronic Solutions

2. DELIVERABLES

- DSP c-code for inverter for closed loop vector control of a generator
- FPGA firmware for controllable interlock delays and AtoD channel interfacing
- 2 x FPGA cards for the miniaturized control platform, including installation within the new control platform box
- Reworking and operation testing of two of the new control platforms at our laboratories in Nottingham

All the above was housed in a box with identical connectors to the existing United Defense control platform.

- Four progress reports as stated in the contract
- Advice given to the ARL team on various issues regarding the large inverter

3. VISITS

Visit 1 Dr Andrew Trentin and Dr Pat Wheeler

This visit focused on the application of the Vector Control routines on the TI 67C13 control platform for the large inverter in order to control the generator, shown in figure 1, which will be used by ARL for testing at the SIL. Before the visit basic machine parameters were obtained from ARL to allow design and modeling of the required control loops. During this modeling process it became obvious that the machine had been designed with a very low inductance, and that this would make the current control very difficult to achieve with the switching frequencies achievable with the inverter. Therefore additional inductance was provided to smooth the current waveforms.

The generator had been fitted with a resolver to allow speed feedback. The current transducers from the inverter, which are used for the induction machine control, were also used for the generator control.

The goal of this visit was to sort out all the interfacing required between the inverter and the generator and then to test the generator under closed loop control. It was only possible to do this in motoring mode as there was no engine available to drive the generator, however all the control principles are independent of the direction of power flow, so this is not a major element of risk in the research programme.

By the end of the visit the generator was successfully controlled in motoring mode, although further work to improve the control will be required before final testing of the generator at full power.

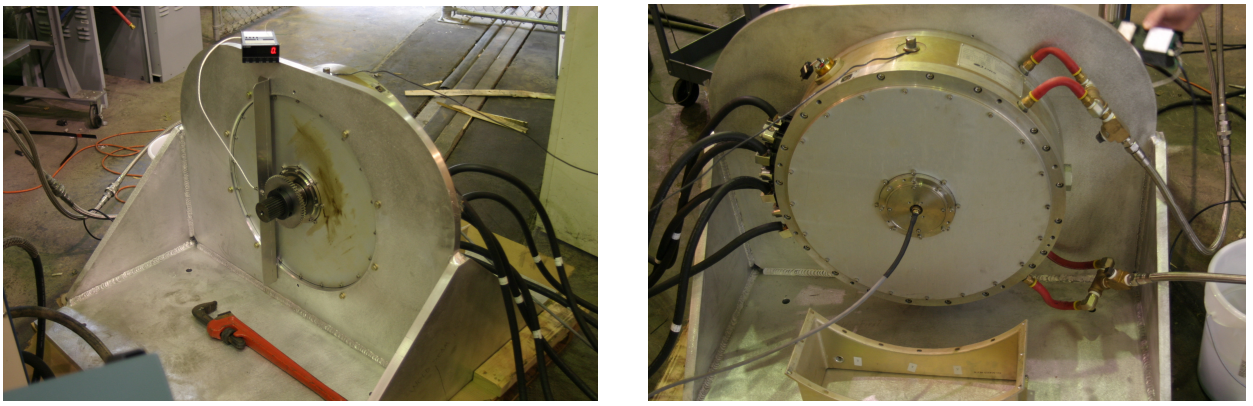


Figure 1: The Generator on a Test Bed at the ARL Research Laboratories

Visit 2: Dr Andrew Trentin and Dr Lee Empringham

The purpose of the visit to the System Integration Laboratory in San Jose by Dr Lee Empringham (UoN), Dr Andrew Trentin (UoN) and Dr Robert Wood (ARL) was to commission a high power inverter system. The trip was considered to be both successful and unsuccessful. While the objective of delivering a working inverter drive which integrates with the SAIC control structure was not completely fulfilled, key milestones were achieved. The inverter was shown to start and transfer power to and from the diesel-generator arrangement. Development was however hindered by HERMIT system problems which needed to be addressed.

The initial rebuild and test of the controller platform went smoothly. The inverter system was tested using a separate power supply to the main DC bus of the HERMIT. The current controllers were seen to function correctly so the inverter was connected to the main DC bus. Initial testing was hindered by intermittent problems with different parts of the HERMIT system.

The battery management system uses a simple potential divider to detect earth leakage faults. The problem was that different parasitic resistances exist on the network and hence change the effective values of the potential divider changed and any small amount of power flow caused a trip. This problem was solved with the addition of compensating resistors to the network to re-balance the battery potential divider. This may need to be re-addressed as the configuration of the network/bus changes.

When the DC-DC converter worked correctly, the ARL inverter was used to drive and start the diesel engine. The problems with the DC-DC converter which included, 900A current spikes into the ARL inverter, DC bus collapse for no reason, were discovered, during the second week, to be due to it re-booting during the start up of the ARL inverter. No immediate solution could be found so the DC-DC converter was changed. This solved the problems but was seen to offer poor control of the DC bus voltage compared to the original but it allowed the work to continue.

Tests to draw power from the diesel generator failed because the master controller of the HERMIT (labview system) was not able to increase the throttle and hence speed of the diesel engine. This was due to the input signal to the diesel engine being too noisy. This was potentially due to EMI from the ARL inverter but an EMI susceptible voltage signal was used for the demand. This was then converted to a current signal in an attempt to improve the system but the source voltage signal was noisy. The system was improved the addition of a large filtering capacitor across the burden resistor close to the engine controller. At this point initial tests were performed to transfer a small amount of power from the diesel generator to the DC bus.

Conducted/radiated noise generated by the inverter was a big problem during the visit. SAIC informed us that another inverter in their system suffered the same problem. It could not be decided however whether the root of the problem was increased levels of noise from the inverters, poor physical layout or over-

susceptibility of the whole system to EMI. The key to the success of this project will be in the improvement in the levels of EMI or susceptibility to it. The remainder of this document will concentrate on the strategic objectives necessary to complete the goal of delivering a working converter to SAIC. It also highlights potential improvements to the existing HERMIT set up which may help SAIC in achieving their goals.

The inverter was shown to work but significant system integration issues remain and need to be remedied prior to another commissioning visit.

Some suggestions as to what we can do to improve the inverter system:

1. Improve the gate drive board: This will give the possibility to insert some capacitance between the terminals of the DC bus and chassis to reduce the noise. This should be tested before it is shipped back to SAIC.
2. Recalibrate the A2D: Full resolution of the A2D channel should be set for a maximum current of 800A. This will help the control, and the current ripple.
3. Increase the capacitance in the DC link: This will improve the quality of the output voltage, and reduce the ripple of the current in the dc link and in the output phase of the converter (can we add 2-4mF? Can we use electrolytic?).
4. Improve the performance of the current PI in my control: This would improve the performance.

To progress with this work we need to know form SAIC

1. A connection diagram of the PM (DRS) would be useful to see if there are any inherent problems with the methodology chosen. (are the two star points connected to the same point?)
2. A connection diagram of all connections of different components and supplies to the chassis would be useful.
3. We would like to understand the connections (relative to ground and chassis) of the previous inverter used to control the PM (DRS) so we can compare to the present system.
4. Why does the DC/DC converter sometimes reboot when we start? What are the conditions or signals to cause a reboot for the dc/dc converter? Does that signal come from the master control? If yes, is it a digital signal or analogue? Does the controller have an isolated supply or does it use the noisy 28V system?

It is hoped that this demonstration work can be continued in the near future once unrelated issues regarding the prime mover are resolved.

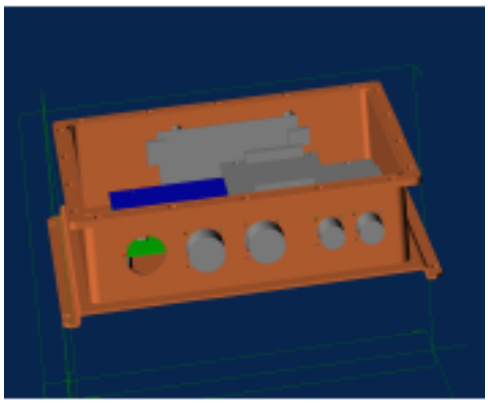
Visit 3: Dr Andrew Trentin, January 2008

At the end of January 2008 Andrew Trentin will travel to ARL in order to demonstrate the new control platform with the existing code and target hardware in the ARL laboratories. A spare set of hardware has also been built and shipped to ARL in case of any commissioning problems. Interfaces with data acquisition and monitoring systems have also been checked and minor problems resolved.

Related Work Undertaken

Working with a third party [Mann Electronic Solutions], a new embodiment of control platform has been developed. The goal of this work was to reduce the size of the control platform and remove the reliance on the supply of DSP Evaluation Boards and associated daughter cards. The new DSP card interfaces with a revised FPGA and data acquisition card provided by the University of Nottingham. During the design phase we worked very closely with Mann Electronic Solutions in order to define the requirements of the new DSP board and to ensure that it would interface successfully with the FPGA and data acquisition card. Once these interface definitions were defined the new DSP board was designed and built by Mann Electronic Solutions.

The first board to be produced was then sent to the University of Nottingham for testing and evaluation. When the board arrived in Nottingham it was combined with our FPGA card. After the resolution of a number of connection issues the board has been tested on an inverter test bed in our laboratories before shipping to the ARL labs.



Autocad drawing of new control in box

4. PAPERS

Published and presented

[1] Fan Yue, Patrick Wheeler, Nick Mason, Lee Empringham and Jon Clare, "Indirect Space Vector Modulation for a 4-Leg Matrix Converter", Power Electronics Specialists Conference, June 2007

[2] Andrew Trentin, Pericle Zanchetta, Robert Wood, Wes Tipton, Patrick Wheeler, Jon Clare "Use of Generic Algorithms for the Optimization of Vector", European Power Electronics Conference, September 2007

[3] Fan Yue, Patrick W. Wheeler, Lee Empringham, Nick Mason and Jon C. Clare, "A New Control Method of Single-stage 4-Leg Matrix Converter", European Power Electronics Conference, September 2007

[4] Katsis. D, Wheeler P.W., Clare J.C., Zanchetta P., Empringham L., Bland, M, "A Utility Power Supply Based on a Four-Output Leg Matrix Converter", IEEE Transactions on Industrial Applications, August 2007.

[5] Andrew Trentin, Pericle Zanchetta, Robert Wood, Wes Tipton, Patrick Wheeler, Jon Clare "Performance Assessment of SVM Modulation Techniques for Losses Reduction in Induction Motor Drives", IEEE Industrial Application Society Annual Meeting, October 2007

[6] Zanchetta P., Wheeler P.W., Clare J.C., Katsis. D, "Control of a Four-leg Matrix Converter to a Utility Power Supply Application", IEEE Transactions on Industrial Electronics, January 2008.

[7] Katsis. D, Wheeler P.W., Clare J.C., Zanchetta P.,Empringham L., N Mason, Bland, M, "A Utility Power Supply Based on a Four-Output Leg Matrix Converter", IEEE Transactions on Industrial Applications, accepted for publication in 2008.

Further conference and journal papers are planned.